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GB 2151848 A **GB 2151793 A** **EP 0188771 A2**
US 4776924 A **US 4324137 A**

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UK CL (Edition N) **C7F FGA FGZ FPEE FPEM FPEX , G1N NAGBR NAGB1 NAGB10 NAGB3 NAGB4 NAGB5**
INT CL^6 **C23C 4/08 14/14 14/16 14/18 14/20 , G01D 5/20**
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(54) **Transducer cores**

(57) Transducer cores, and methods of making the same, are provided in which a coating of magnetically soft material is applied, preferably by a spray coating process, over at least part of the surface of a transducer core body. Good magnetic properties are achieved while substantially simplifying the construction and production method for transducer cores, allowing highly reliable cores to be produced more easily and more cheaply than heretofore. The coating may include silicon, alumina or chromium oxide. The embodiment shown is for a linear inductive measurement transducer, but cores for angular and incremental measurement transducers are also described.

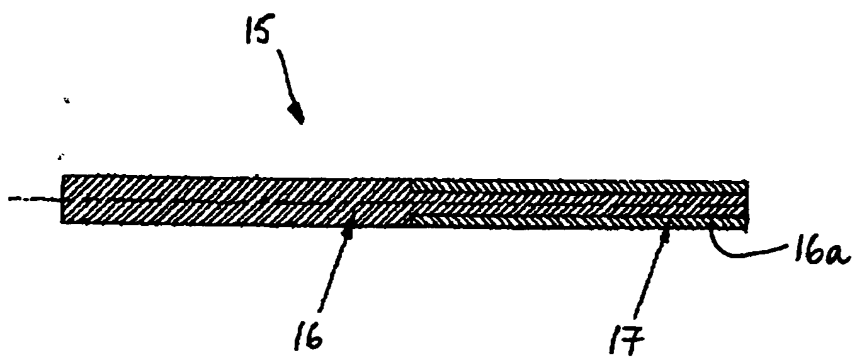

Fig. 5

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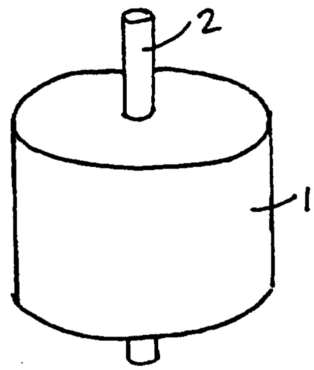

Fig. 1

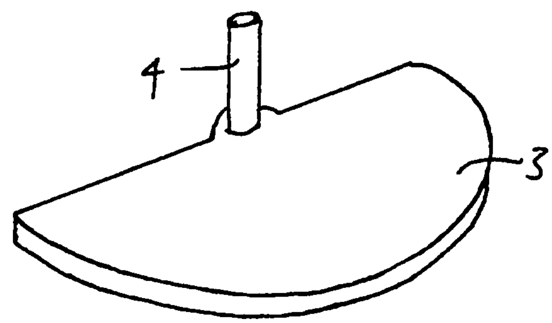

Fig. 2

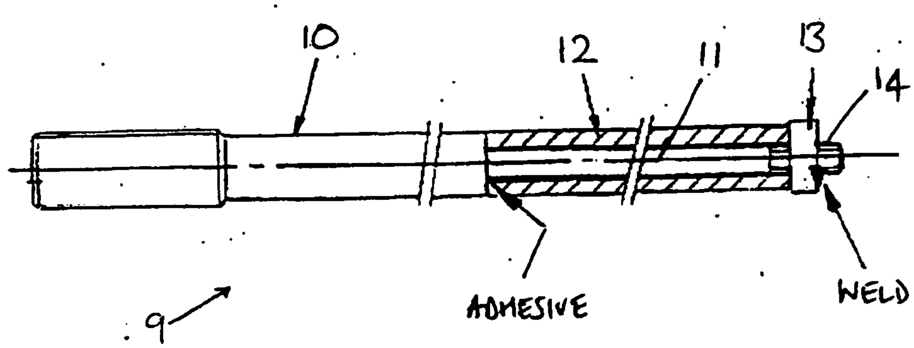

Fig. 4

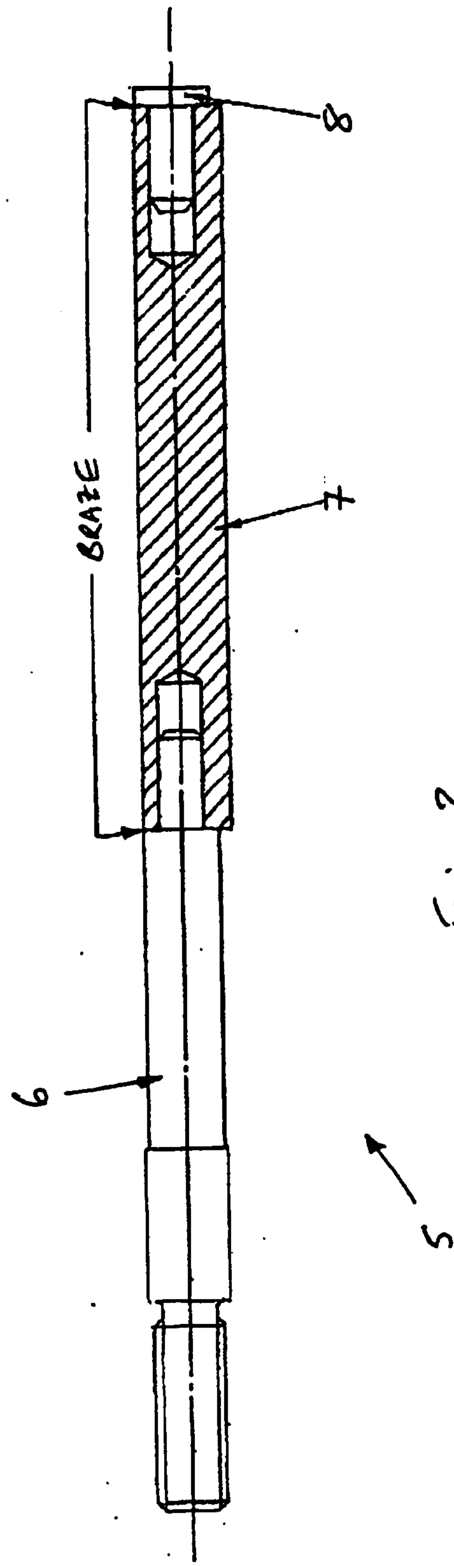

Fig. 3

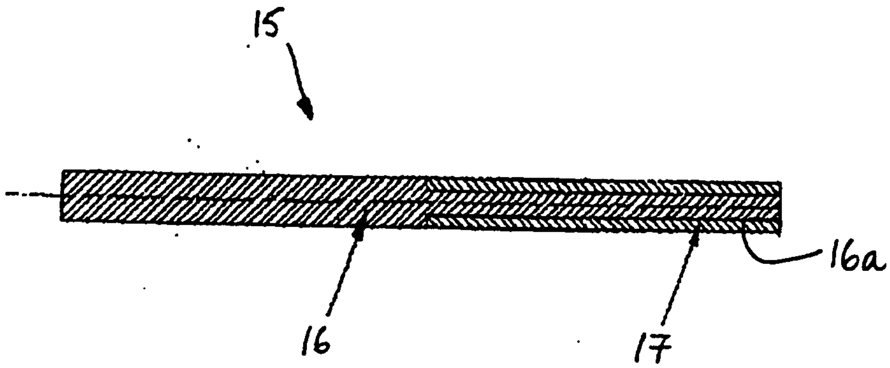

Fig. 5

Fig. 7

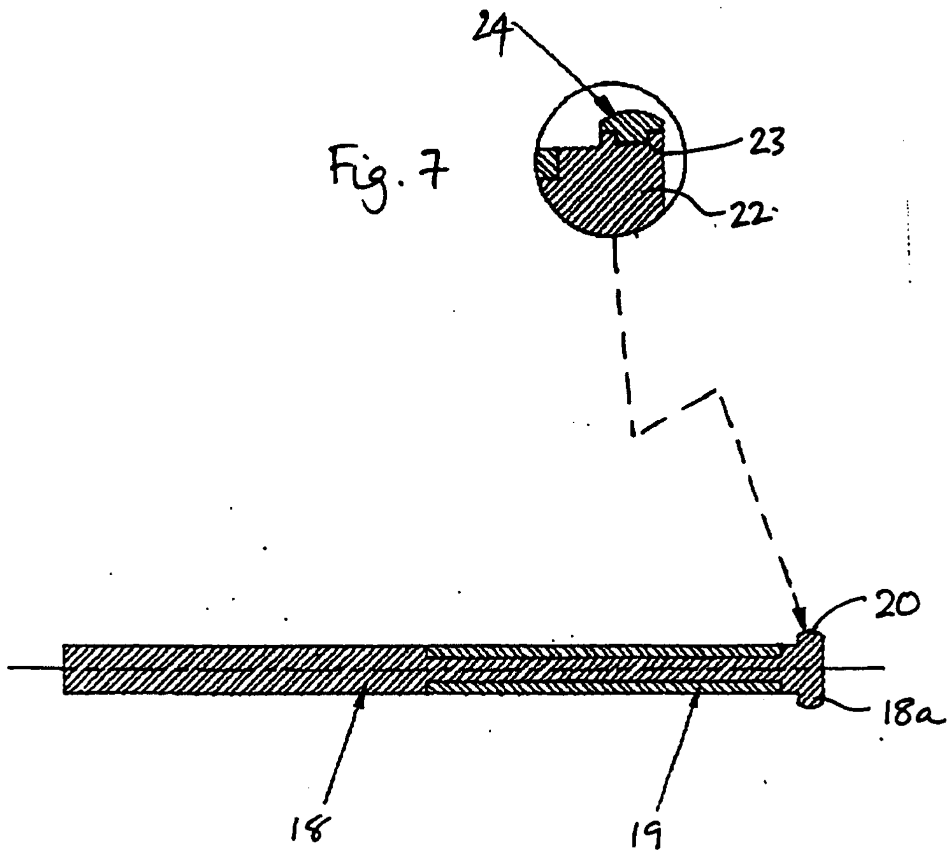

Fig. 6

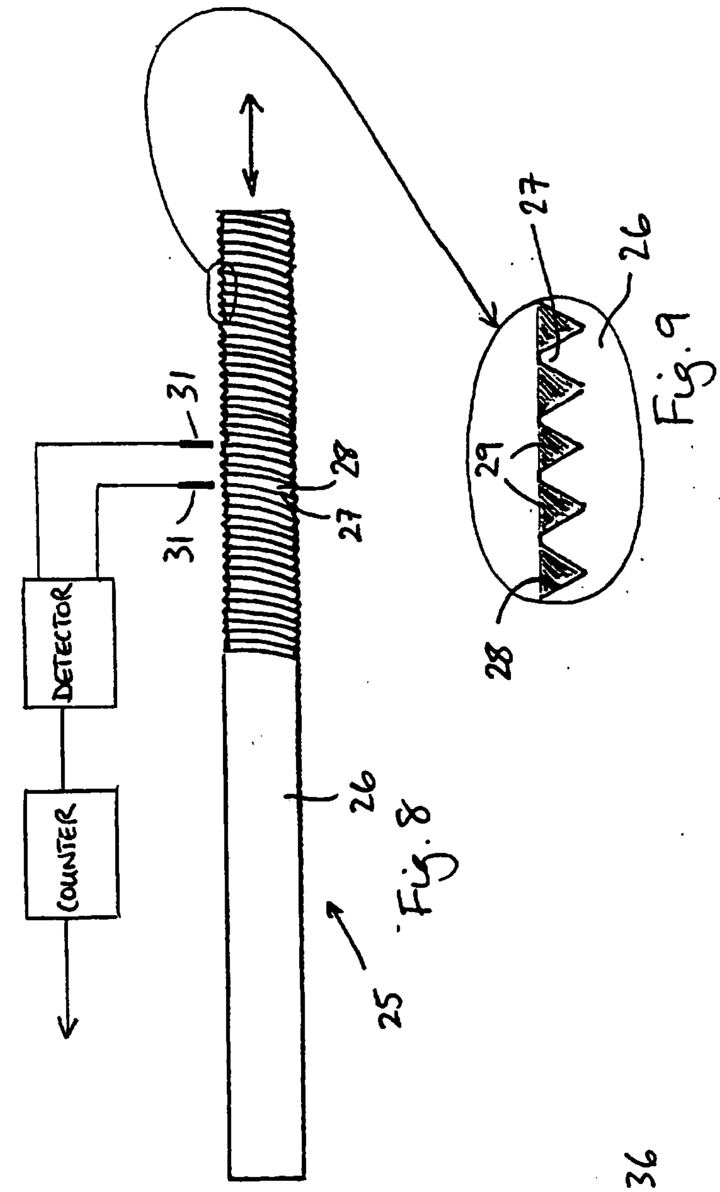

Fig. 8

Fig. 9

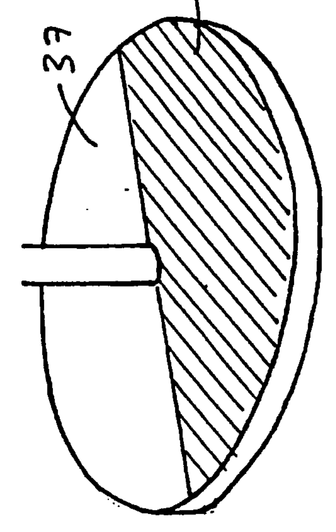

Fig. 11

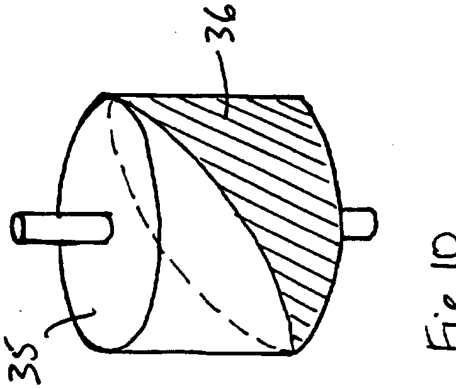

Fig. 10

TRANSDUCER CORES

This invention relates to transducer cores, transducers employing the transducer cores, and methods of making the cores. The invention finds particular application in the field of transducers operating by magnetic principles, such as inductive transducers, where a magnetically permeable member, or core or armature, is moveable relative to a sensor, usually a winding, and an output signal is generated which is indicative of the relative displacement of the core and sensor.

There are many forms of such transducers, and the cores vary in shape and construction depending on the particular construction and operation of the transducer. The magnetic properties of the core are of course important, and to this end at least part of the core comprises a magnetically soft material, ie. a material with high magnetic permeability which retains substantially no magnetism in the absence of an external field.

In general, the cores are made either by machining a solid mass of magnetically soft material into the desired core shape, or by securing a component made of magnetically soft material to a core body structure. Typical examples of the first type of core, here for rotary transducers where the transducer output varies with angular displacement of the core, are shown in Figures 1 and 2.

In Figure 1, the core comprises a solid cylinder of magnetically soft material, such as soft iron, rotatable about a spindle 2. In Figure 2, the core comprises a flat, generally semi-circular soft iron plate 3 mounted for rotation on a spindle 4. These types of core are, however, expensive and difficult to machine to the required shape from a solid mass of core material.

Two examples of the second type of core are shown in Figures 3 and 4, here for linear transducers where the transducer output varies with linear displacement of the core. In Figure 3, the core, generally indicated at 5, comprises a shaft 6, a core element 7 of soft magnetic material, and an end cap 8, constructed as shown. The core is thus made in three distinct parts, the core element 7 being fitted over the end of the shaft 6, and the end cap 8 being fitted into the end of the core element 7 as shown in the figure. The core element 7 is

heat-treated prior to assembly with the shaft to improve its magnetic properties. The components of the core 5 are secured by brazing at the points shown, care being taken during this process to ensure that the core is not knocked which may impair its magnetic properties.

In the example of Figure 4, the core 9 comprises a shaft 10, having a narrowed extension 11 for receiving a tubular core element 12 as a sliding fit. Here, the heat-treated core element 12 is fitted over the shaft extension 11 to which a small amount of adhesive has been applied at the point shown, and a lock nut 13 with screw 14 is fitted to the end of the core element 12. The screw 14 is then screwed into the threaded end of the shaft extension 11 and welded at the point shown to secure the assembly.

Various other similar multi-part core constructions are known which use welding, brazing, screw clamping or mechanical deformation, or a combination thereof, to secure the parts together. A number of problems are associated with these constructions. For example, reliability and positional stability of the resulting core assemblies can be effected by the multi-part construction, and core clamping stresses, weld, or braze stresses can be high due to magneto resistive effects. Also, the high parts count increases costs, as does the need for secondary assemblies for welding, brazing etc., and the number of separately dimensioned parts involved leads to high tolerance build-up.

In accordance with one aspect of the present invention there is provided a transducer core comprising a core body having a coating of magnetically soft material over at least part of the surface thereof.

In accordance with another aspect of the invention there is provided a method of making a transducer core, the method comprising applying a coating of magnetically soft material over at least part of the surface of a transducer core body.

In accordance with the invention, therefore, the magnetically soft core material is simply applied as a coating to the core body, whereby some or all of the problems described above can be alleviated or avoided altogether. The magnetically soft material is preferably applied by a spray coating process, such as wire flame spraying, powder flame spraying, electric arc spraying, or, as is preferred, a plasma spraying process. In such thermal spray processes, the spray coating can be produced from material in powder or wire form, for example, the

material being melted by a heat source and projected onto the core body to the form the coating. Even though it might be thought that the desired magnetic properties of the magnetic core material could not be maintained with such a process, it is found that perfectly acceptable results are achieved while at the same time the problems described above can be avoided.

The core body can conveniently be integrally formed, preferably of a metallic material which is substantial non-magnetic, ie. with a relative permeability close to unity as compared with the magnetically soft coating material. The coating material can be any material which provides the desired magnetic properties, for example an alloy such as nickel-iron. The composition of the coating material can be varied to improve the characteristics the resulting coating as desired. For example, oxides or other ingredients, such as silicon, may be included to improve oxidation characteristics, increase resistivity, or reduce eddy current losses for example. Aluminium or chromium oxides for example, with high resistivity, modify the loss characteristics and improve higher frequency operation of the resulting transducer. As a further example, cobalt alloys can improve the saturation characteristics of the resulting coating.

It is to be appreciated that, in general, where features are described herein with reference to an apparatus embodying the invention, corresponding features may be provided in accordance with a method embodying the invention, and vice versa.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

Figures 1 to 4 illustrative examples of prior transducer core constructions;

Figure 5 illustrates one example of a transducer core embodying the invention;

Figure 6 illustrates another example of the transducer core embodying the invention;

Figure 7 illustrates a modification to the core of Figure 6;

Figure 8 illustrates schematically a transducer embodying the invention using an alternative form of core;

Figure 9 is an enlarged view of part of the core of Figure 8;

Figure 10 shows another example of a core embodying the

invention; and

Figure 11 illustrates a further example of a core embodying the invention.

The embodiment of Figure 5 illustrates a transducer core 15 for a linear inductive transducer. The core 15 comprises a core body 16 in the form of a generally cylindrical elongate shaft having a section of narrower diameter at one end to form a recessed surface 16a over this section. The shaft 16 is formed of a high strength material, such as a nickel-chrome steel or phosphor-bronze. A coating 17 of magnetically soft material, in this example nickel-iron, is applied over the recessed surface 16a to a thickness equal to the depth of the recess so as to lie flush with the surface of the larger diameter portion of the shaft 16. Such a transducer core is typically mounted for movement along its longitudinal axis relative to a winding which may be supported in a cylindrical housing into which the core 15 can be inserted or withdrawn.

The core 15 is made as follows. Firstly, a cylindrical shaft of diameter corresponding to that of the larger diameter portion of the shaft 16 is machined in known manner to form the recessed surface 16a at one end thereof. The depth of the recess will depend on the desired depth of coating which in turn depends on the desired magnetic properties. An example might be $^{15}/_{1000}$ inch, although generally the properties will improve with coating depth.

Next, the shaft is mounted for rotation about its longitudinal axis, and the shaft is rotated as the recessed section is spray coated with the nickel-iron coating using a known plasma spray gun. In the plasma spraying process, a plasma forming gas such as argon or nitrogen is ionised by a high voltage electric arc in the spray gun. The ionised gas is forced through a nozzle, liberating extreme heat as the gas exits the nozzle. Coating material in powdered form is injected into the hot gas stream where it is melted and projected at high velocity by the gas onto the recessed portion of the shaft. This process may be performed in air or, if desirable, in vacuo. The coating material is generally applied to a thickness slightly greater than the depth of the recess, and may also coat the surface of the shaft immediately adjacent to the recess. After cooling, the shaft is simply machined to remove excess material leaving a coating of

thickness equal to the depth of the recess. The shaft can then if necessary be heat-treated in a vacuum furnace to a temperature above about 700°C, typically to a temperature of about 1100 to 1150°C. This heat-treating can improve the magnetic properties, in particular the magnetic permeability of the coating, and can also assist in providing repeatability in the core production process, since some cores may require more machining than others in production and therefore have substantially different magnetic properties prior to heat-treatment.

Figure 6 shows an alternative embodiment of a linear transducer core, in which the shaft 18 has an enlarged end portion 18a adjacent to the recessed section to which the magnetically soft coating 19 is applied as in the earlier embodiment. The enlarged end portion 18a provides an annular bearing surface 20 to bear against the interior of the transducer housing and stabilise movement of the core. The bearing surface 20 may be provided by the material of the shaft itself if this has good bearing properties such as, for example, phosphor-bronze. An alternative embodiment is illustrated in Figure 7 which simply shows an enlarged view of a portion of the end of the core corresponding to the portion indicated by the arrow to Figure 6. Here, the core body 22 is identical to the shaft 18 except that the shaft is formed of stainless steel and the enlarged end portion is formed with an annular recess 23 to which a coating 24 of a suitable material, such as aluminium-bronze, is applied by a spray coating process as described above, and then machined to provide the bearing surface.

The above embodiments demonstrate substantial advantages over the prior linear transducer core constructions described with reference to Figures 3 and 4. In particular, the embodiments provide high reliability single part shafts without the need to clamp, weld or braze a separately formed magnetic core element in position. The production process is substantially simplified, and costs can be reduced due to the lower parts count and removal of the need for secondary assemblies such as for welding, brazing or material deformation. There is a lower tolerance build-up from a given datum since there are fewer separately dimensioned parts, and positional stability of the core assembly can be substantially improved. Core clamping stresses, weld or braze stresses are inhibited, and the magnetically soft material can be heat-treated in situ on the shaft, thus avoiding impairment of the magnetic

properties of the core element which can occur during assembly of the prior cores.

In the embodiments described above, the core material is applied to the recessed section around the full circumference of the shaft. It may be desirable to machine only part way around the circumference of the shaft, leaving a narrow strip of unmachined shaft along the length of the recessed section, to reduce eddy current losses in the resulting part-cylindrical magnetic coating. Also, in the above embodiments the shaft is machined to provide a recess in which the coating material is applied since the annular shoulders of the shaft at the ends of the recess provide accurate, well-defined ends to the magnetically soft coating after machining. Although this is preferred, a cylindrical shaft could be masked to define the area over which the coating is to be applied, removal of the masking material after the spray coating process leaving a defined coated region, in which case machining of the shaft to form a recessed section can be avoided.

It will be appreciated that, while the above embodiments show cores for single-lane transducer, so that only one section of the core body is coated, cores can be formed for multi-lane devices simply by applying coating material over a number of spaced sections of the shaft as required.

Figure 8 is a schematic diagram of one embodiment of a transducer using a core of different construction. In this embodiment, the core 25 again comprises a core body 26 in the form of an elongate cylindrical shaft. In this case, however, the shaft 26 is machined with a screw thread 27 over the end section thereof so that a helical groove 28 is defined between the threads. Again, a coating of magnetically soft material such as nickel-iron is applied by a spray coating process to the threaded portion of the shaft, and excess material may then be removed by machining so that the helical groove 28 is left filled with nickel-iron as shown in Figure 9.

This structure gives a periodic variation in the permeability of the shaft surface along the length of the threaded portion, and this can be utilised to produce an incremental-type transducer. In particular, as indicated schematically in Figure 8, the transducer can include sensor means comprising a detector 30 and two sensors 31 which may comprise coils, magneto resistors, or Hall effect devices for

example. The sensors 31 pick-up variations in magnetic field due to the varying reluctance of the respective adjacent portions of the core 25 as the core is moved in its longitudinal direction relative to the sensors and successive turns of the screw thread move past the sensors. The sensors 31 are spaced apart by an integral number of turns plus or minus one quarter of the turn pitch so that the sensor output signals are 90° out of phase with one another. The sensor outputs are supplied to a detector 30 which determines the direction of movement of shaft 26 in known manner according to which of the sensor output signals leads the other. The detector 30 determines when each turn of the helical groove (or thread) passes a fixed point (the position of one of the sensors 31) and increments (by plus or minus one depending on the direction of movement of the shaft) a count stored in a counter 32 which forms the transducer output.

The transducer of Figure 8 is thus an incremental device the output of which varies incrementally with the relative position of the core 25 and sensors 31. While this embodiment demonstrates one convenient implementation in which a helical groove is provided by machining a screw thread, a helical groove is not essential to the operation. For example, the shaft could be provided with a plurality of equispaced circular grooves around its circumference in which the coating material is applied. In this case, the transducer would be unaffected by rotation of the shaft about its axis. Also, where only linear displacement is to be detected, various other implementations can be envisaged in which a series of equispaced regions with magnetically soft coatings are provided on a core body (which need not be a cylindrical shaft) along the direction of linear movement. Further, rotary incremental devices can be implemented using the same principles. For example, a generally cylindrical core body, rotatable about its axis relative to the sensor means, may be provided with angularly spaced regions of magnetically soft coating around its outer surface, to provide a rotary incremental device such as a rotary position encoder, shaft speed sensor or turns counter. Similar devices may be implemented for example with a disc-shaped core body with angularly spaced coated regions on the surface thereof.

The invention can of course be applied to advantage in other types of transducer to those described above. For example, referring

to the prior transducer core of Figure 1, in an embodiment of the present invention, this type of core can be made by spray coating with a magnetically soft material a cylindrical core body made of any suitable material, in particular a material which is easier to machine than the solid mass of magnetic material from which the prior core is produced. Cores of this type can therefore be made more easily and more cheaply than before. As a further example illustrating the flexibility of the spray coating process in these applications, Figure 10 shows a core comprising a generally cylindrical core body 35 with a spray coating of magnetically soft material over one half of the exterior cylindrical surface of the body as indicated at 36. The difficulties of achieving an equivalent structure by prior methods will be appreciated, and of course this is only one example and numerous other configurations may be envisaged. As a further example, a core embodying the invention with an equivalent function to the prior core of Figure 2 is illustrated in Figure 11. Here, a core body comprising a flat disc 37 of substrate material has a spray coating of magnetically soft material applied over substantially one half of the upper surface thereof. Again, the embodiment of Figure 11 can be made more easily and cheaply than the equivalent structure of Figure 2 which is formed by machining the solid mass of magnetically soft material.

In some embodiments of the invention a plurality of coatings may be applied to the core body. For example, magnetically soft coating layers may be alternated with thin insulating layers, eg titanium or aluminium oxide layers or tungsten carbide layers, which may be also applied by a thermal spray process, to produce a laminated structure in which eddy current losses are reduced by cancellation in adjacent layers. In other embodiments, for example, a protective coating such as a wear-resistant coating or an oxide-resistant coating, or a coating with good bearing properties may be applied over all, or part, as necessary, of a core body to which the magnetically soft coating material has previously been applied. The material for such an additional coating can be selected to give the desired properties, but, for example, tungsten carbide may be used to give wear resistance, aluminium-bronze may be applied for good bearing properties, and aluminium oxide may be applied for oxide resistance.

While a plasma spray process has been particularly described

above for applying the coating material, other coating processes may be used if desired, such as wire flame spraying or powder flame spraying, in which coating material in wire or powder form is melted in an oxygen-fuel gas combustion flame and projected onto the substrate, or electric arc spraying for example, in which an arc is struck between two electrically charged wires of coating material, and compressed air is used to atomise and spray the molten material onto the core body. It will of course be appreciated that many other variations and modifications may be made to the specific embodiments described above without departing from the scope of the invention.

CLAIMS

1. A transducer core comprising a core body having a coating of magnetically soft material over at least part of the surface thereof.

2. A transducer core as claimed in claim 1, wherein the core body is integrally formed.

3. A transducer core as claimed in claim 1 or claim 2, wherein the core body comprises an elongate shaft, and wherein the coating material is applied over the surface of a section of the longitudinal extent thereof.

4. A transducer core as claimed in any preceding claim, wherein the core body comprises an elongate shaft having a recessed surface over at least a section of the longitudinal extent thereof, and wherein the coating material is applied over the recessed surface.

5. A transducer core as claimed in claim 3 or claim 4, wherein the coating material is applied over the surface of a plurality of sections of the longitudinal extent of the shaft.

6. A transducer core as claimed in claim 1 or claim 2, wherein the coating material is applied to a plurality of angularly or linearly equispaced regions of the core body.

7. A transducer core as claimed in any one of claims 1, 2 or 6, wherein the core body comprises a cylindrical shaft having a helical groove in the surface thereof, and wherein the coating material is applied in the helical groove.

8. A transducer core as claimed in any preceding claim wherein a plurality of coatings are applied to the core body, at least one coating being of magnetically soft material.

9. A transducer core substantially as hereinbefore described with reference to Figures 5 to 11 of the accompanying drawings.

10. A transducer including a transducer core as claimed in any preceding claim.

11. A transducer comprising a transducer core as claimed in claim 6, and sensor means, the core being rotationally or linearly movable relative to the sensor means such that successive said regions move past the sensor means, and the sensor means being responsive to the change in permeability of the adjacent portion of the core as successive said regions move past the sensor means, wherein the transducer includes counter means, responsive to the sensor means, for incrementing a count as successive said regions move past the sensor means.

12. A transducer comprising a transducer core as claimed in claim 7, and sensor means disposed adjacent to the grooved portion of the core, the core being movable relative to the sensor means in the longitudinal direction of the core, and the sensor means being responsive to the change in permeability of the adjacent portion of the core as the turns of the helical groove move relative to the sensor means, wherein the transducer includes counter means, responsive to the sensor means, for incrementing a count as successive turns of the helical groove move past the sensor means.

13. A method of making a transducer core, the method comprising applying a coating of magnetically soft material over at least part of the surface of a transducer core body.

14. A method as claimed in claim 13, wherein the magnetically soft material is applied by a spray coating process.

15. A method as claimed in claim 13 or claim 14, including machining the core to remove excess coating material after the coating process.

16. A method as claimed in any one of claims 13 to 15 including heat-treating the core after the coating process.

17. A method as claimed in any one of claims 13 to 16, including

forming an integral core body to which the coating material is applied.

18. A method as claimed in any one of claims 13 to 17, wherein the core body comprises an elongate shaft, comprising machining a section of the shaft to form a recessed surface, applying the coating material to the recessed surface to a thickness greater than the depth of the recessed section, and machining the coating material to a thickness equal to the depth of the recess.

19. A method as claimed in any one of claims 13 to 18, comprising applying a plurality of coatings to the core body, at least one of the coatings being of magnetically soft material.

20. A method or apparatus as claimed in any one of the preceding claims, wherein the coating material comprises an alloy.

21. A method or apparatus as claimed in any one of the preceding claims, wherein the coating material comprises a nickel-iron alloy.

22. A method or apparatus as claimed in any one of the preceding claims, wherein the core body comprises a substantially non-magnetic metallic material.

23. A method of making a transducer core, the method being substantially as hereinbefore described with reference to Figures 5 to 11 of the accompanying drawings.

13

Patents Act 1977 **Examiner's report to the Comptroller under Section 17** **(The Search report)**	Application number GB 9517811.7
Relevant Technical Fields (i) UK Cl (Ed.N) C7F (FGA, FGZ, FPEE, FPEM, FPEX); G1N (NAGB1, NAGB3, NAGB4, NAGB5, NAGB10, NAGBR (ii) Int Cl (Ed.6) C23C (4/08, 14/14, 14/16, 14/18, 14,20); GO1D 5/20	Search Examiner P G BEDDOE Date of completion of Search 14 NOVEMBER 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI, CLAIMS	Documents considered relevant following a search in respect of Claims :- 1-23

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 2151848 A	(INTERNATIONAL STANDARD) see especially Claim 1, Figure 1; page 1, line 83 - page 2, line 30	1,13
X	GB 2151793 A	(INTERNATIONAL STANDARD) see especially Claim 1, Figure 1; page 1, lines 6-8 - page 2, line 4	1, 13
X	EP 0188771 A2	(STANDARD ELEKTRIK) see especially Claim 1, columns 2-3	1, 13
X	US 4776924	(COMMISSARIAT) see especially column 3, line 57 - column 5, line 16	1, 13
X	US 4324137	(ALSIN SEIKI) see especially column 4, line 32 - column 5, line 59; Figures 6a-6d	1,13

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).